Contents lists available at ScienceDirect
Vehicular Communications
www.elsevier.com/locate/vehcom

Content sharing in Internet of Vehicles: Two matching-based user-association approaches

Francesco Chiti [a], Romano Fantacci [a], Yunan Gu [b], Zhu Han [b]

[a] University of Florence, Florence, Italy
[b] University of Houston, Houston, USA

ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 26 September 2016
Accepted 15 November 2016
Available online xxxx

Keywords:
Internet of Vehicles
Content sharing
User association
Clustering
Matching theory

ABSTRACT

The new era of the Internet of Things is driving the evolution of conventional Vehicle Ad-hoc Networks (VANETs) into the Internet of Vehicles (IoV), where a variety of applications, such as road safety, traffic efficiency, driver assistance and so on, have been envisioned. Benefiting from the 3GPP study case on the LTE assisted vehicular communications, the information dissemination within IoV can become more reliable and efficient, thus enabling some safety critical applications. This paper discusses the user association methods to optimize the information dissemination in IoV. With joint consideration of vehicles' quality of service (QoS) requirement (i.e., the communication link quality) and the information gained through communication (i.e. the data value), the user association problem is formulated as a mix integer linear programming (MILP) problem. In pursuit for distributive solutions, two matching-based user association methods are proposed. The first method is clustering based, modeled as the hospital resident (HR) matching game. In particular, a stable matching between the cluster heads and ordinary nodes can be achieved with the proposed resident-oriented Gale–Shapley (RGS) algorithm. The second user association method provides an independent and equal relationship between vehicles, different from the ordinated/coordinated relation in the clustering method. The stable fixture (SF) model is adopted to model such relations; the so-called Irving's stable fixture (ISF) algorithm is utilized to find a stable matching within the vehicles if one exists. The performance of the two proposed approaches is evaluated under different traffic scenarios w.r.t. network connectivity, network partition and overall data exchanged, by comparing the proposed approaches with some heuristic algorithms. The simulation results point out that both matching-based approaches are capable of achieving high performance, highlighting also good stability, flexibility, scalability and affordable complexity.

1. Introduction

The Internet of Vehicles (IoV) is a convergence of the mobile Internet and the Internet of Things (IoT), which encompasses information communication, environmental protection, energy conservation, and safety. It enables information sharing and gathering of information on vehicles, roads and their surrounds [1,2]. With the rapid development of computation and communication technologies, IoV promises huge commercial interest and research value, and, thus, attracting a large number of companies and researchers [3]. To this purpose, it is worth noting that the outcomes of standardization activities, in particular IEEE 802.11p, IEEE 1609 in USA, ETSI ITS (Intelligent Transportation System) and ISO CALM (Continuous Air-interface Long and Medium range) in EU, proposed enhanced communications paradigms involving both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications for information sharing [4]. The different proposal, however, presents an evolutionary trend leading to a convergence towards an *integrated* protocol stacks, as previously pointed out in [5]. In particular, it is evident an increasing degree of interoperability with different air interfaces both at the Physical and MAC layers, while the higher layers are expected to be unified by the adoption of IPv6 oriented protocols.

The technological evolution is paving the way to a new generation of *smart cars*, which integrates information processing, communications, control and sensing features. Intelligent vehicles are expected to gather the context information and process it to enhance the driving experience. For traditional IEEE 802.11p based V2X (denoting both V2V and V2I) communications, reliable and efficient performance cannot be guaranteed since 802.11p is

E-mail addresses: francesco.chiti@unifi.it (F. Chiti), romano.fantacci@unifi.it (R. Fantacci), ygu6@uh.edu (Y. Gu), zhan2@uh.edu (Z. Han).

http://dx.doi.org/10.1016/j.vehcom.2016.11.005
2214-2096/

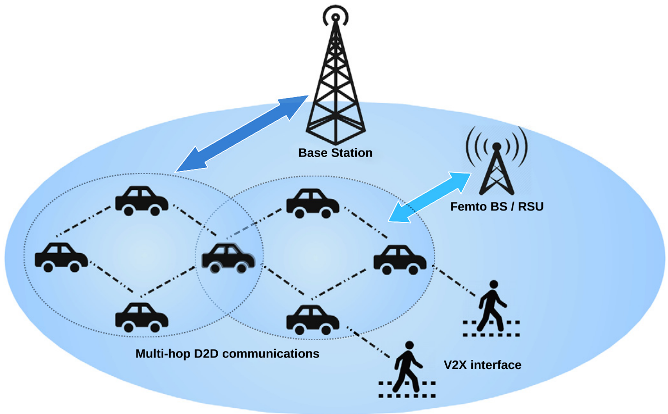

Fig. 1. 5G vehicular communications supporting the proposed application model through multi-hop D2D communication over V2X interface.

CSMA/CA based. Besides, the high cost of deploying road side units (RSUs) cannot be ignored. To this end, in the 5G evolution, LTE has been proposed to integrate into V2X communications to facilitate reliable and high quality communication applications. With the approval of the study item: "Feasibility Study on LTE-based V2X Services" on 3GPP TSG RAN #68, the definition of an evaluation methodology and possible scenarios for vehicular services based on LTE, and the identification, evaluation of necessary enhancements to LTE physical layer, protocols and interfaces have been studied [6]. So far, 3GPP has agreed 18 use cases in TR 22.885 for LTE-based V2X services, such as 5.1: Forward collision warning, 5.8: Road safety services, 5.9: Automatic parking system, 5.18: vulnerable road user safety and so on [7]. LTE-based V2X technology allows low cost and rapid deployment compared with other solutions, since it can fully utilize existing cellular base stations (BSs). In addition, LTE technology features low latency and high reliability communications, and thus making LTE-based V2X communications perfect for safety-critical ITS applications.

In fact, the development of LTE device-to-device (D2D) communication technology, which allows direct communication between users without going through the BSs, has already paved the way for LTE assisted V2X communications. The advantages of D2D communication, such as better spectrum efficiency, network coverage and capacity, can be extended to the vehicular networks if implementing the D2D technology into the LTE assisted V2X communications. More specifically, the LTE D2D-based short-range direct connectivity allows vehicles to exchange critical information with less delay, while every mobile terminal is also in charge of forwarding the packets in order to communicate with farther terminals without relying on cellular base stations. Besides, this novel radio interface allows to introduce the so-called *fog computing* paradigm, which extends the traditional cloud computing by shifting some functionalities, mainly storage, communication, control, and processing at the *mobile* edge of a network [8]. It provides several advantages, including the dynamic and scalable data processing, which can be easily adapted to the specific context with a minimum latency. Fig. 1 shows an implementation case of the D2D based V2X communication, where homogeneous group of vehicles jointly share and process information generated by on-board sensors by means of D2D side-links, with the assistance of macro (femto) base stations (BSs).

Existing work has explored various aspects of the V2X communications (including V2V and V2I communications), such as the packet scheduling, information dissemination, traffic congestion and emergency warning, multiple antenna technique, security and authentication and so on [9]. Among these, information dissemination has always been a hot topic, which enables a wide range of applications for enhancing the traffic efficiency. Typically, the information dissemination/content sharing is accomplished through the cooperation of V2V and V2I communications. For V2I communication, data is exchanged between vehicles and their nearby road side units (RSUs), which contain data downloaded from the Internet as well as data collected from previously connected vehicles. Instead of solely relying on the V2I communication, two neighboring vehicles are also allowed to share/exchange their collected information. Thus, without traveling to many different locations to download data from the RSUs, vehicles more conveniently can also acquire various information from other vehicles. In addition, from the RSUs' perspective, vehicles can provide them with more diverse data after V2V communications and enhance the context awareness. A challenging aspect for such V2X communication is the design of user association strategy, which studies how should vehicles set up communication links with other vehicles and RSUs in order to improve the diversity of data circulating within the sharing network.

1.1. User association

User association plays an essential role in enhancing the load balancing, spectrum efficiency and energy efficiency for the cellular transmission, and substantial efforts have been devoted into this issue. Classical user association strategies, such as the received power based user association rule and the biased user association, have been widely adopted, while some novel approaches, such game theory based modeling and matching game based modeling, are proposed for sophisticated network typologies as well as new network paradigms [10]. When selecting an appropriate association rule for a specific scenario, metrics such as coverage probability, spectrum efficiency, quality of service (QoS), energy efficiency and so on, are typically considered. Similarly for the IoV communication, the user association, which refers to the communication connection scheduling within the vehicles and infrastructures, also requires careful design. Different from the cellular networks, in VANETs, the design metrics majorly focus on spectrum efficiency, QoS and data value. In other words, with limited spectrum resource (75 MHz in the 5.850–5.925 GHz band for DSRC), vehicles expect to set up communication links with other vehicles or infrastructures that offer good link quality and diversed data of their interest.

As the currently most used user association method, clustering is a mechanism of grouping vehicles based on certain metrics such as geographical locations of the vehicles. These groups are called clusters, where each cluster is coordinated by one of the vehicles, referred to as the cluster head (CH) and the rest of vehicles are referred to as the ordinary nodes (ONs) [11]. The CH normally serves as a local coordinator for its cluster, performing intra-cluster transmission arrangement, data forwarding and so on. There have been many existing clustering approaches proposed for IoV, such as the predictive clustering, back-bone based clustering, MAC based clustering and so on [12]. With the optimal CH selected, the information dissemination can be well coordinated. However for any cluster, any ON requiring information update needs to be assisted by the CH, which may result in communication capacity bottleneck in the CH. In addition, ONs may lack the flexibility of setting up connections with any other node who may carry information of their interest. Motivated by the above mentioned reasons, we come up with the idea of proposing a flexible V2X communication framework, where each vehicle plays an equal role and is free to communicate with any vehicle or infrastructure upon its interest. Under such topology, the link connections are independent from each other, and are only relevant with the transmitter and receiver vehicles/infrastructures. However, the design of such a flexible network topology requires joint consideration of some fac-

Please cite this article in press as: F. Chiti et al., Content sharing in Internet of Vehicles: Two matching-based user-association approaches, Veh. Commun. (2016), http://dx.doi.org/10.1016/j.vehcom.2016.11.005